Two-fluid simulations of solar partially ionized atmosphere

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Studying the sun(observations)

- The first written record of sunspots was made by Chinese astronomers around 800 B.C
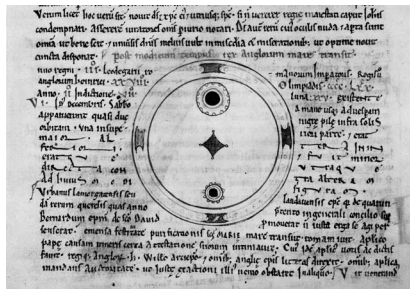- 1982 years before the first drawing

Figure 1: The earliest known drawing of sunspots appears in The Chronicle of John of Worcester and predates the invention of the telescope by almost 500 years. The sunspot was recorded in medieval England in 1182, according to astronomer F. Richard Stephenson at the University of Durham.
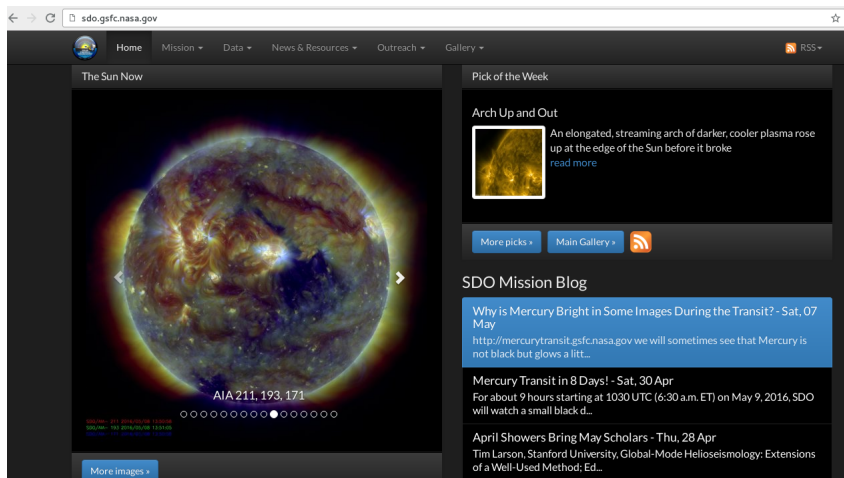
Studying the sun(observations)

Figure 2: SDO space telescope live images of the sun in several wavelengths

Mysteries of the sun
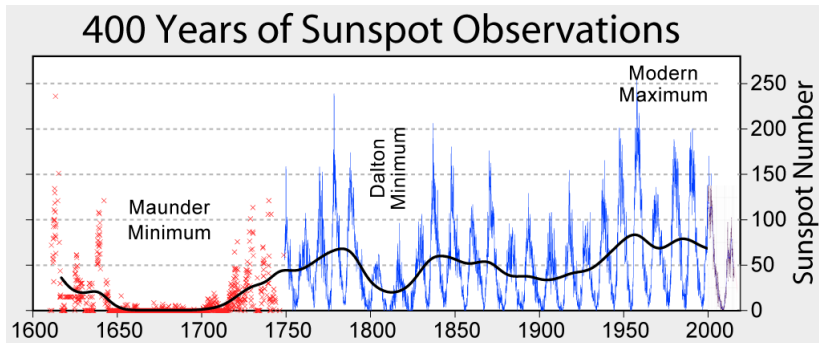
- solar cycle

Figure 3: solar magnetic activity cycle is the nearly periodic 11-year change in the Sun's activity

Mysteries of the sun

- the mechanism of the generation of a magnetic field thousands times stronger than on earth concentrated in spots as large as earth (the sunspots)
- coronal heating: above the photosphere at around 6000 K the temperature rises abruptly at over 1 million degrees

We can only see to a certain depth in the atmosphere so a theoretical model of sun is needed.

Studying the sun(theoretical models)

Sun as a plasma(a gas containing neutral and charged particles, but globally electrically neutral with collective behaviour)

- main sequence star burning hydrogen into helium into its core
- the sun atmosphere is composed mainly of H and He (the estimated proportion of number of atoms H:He is 10:1 and metallicity $Z = 0.0122$)
- neutral atoms in the photosphere start to become ionized in the chromosphere where temperature starts to rise and are fully ionized in the corona

Plasma models

- fluid mechanics equations derived (in statistical physics) from Boltzmann equation for the evolution of variables like density, pressure and velocity
- induction equation derived from Maxwell equations and Ohm law for the evolution of the magnetic field

Plasma models

- system of first order non linear partial differential equations which must be integrated in time
- Approximations:
    - MHD-1fluid: all the particles are considered as a whole. Assumption: strongly collisional plasma. A system of 8 unknown variables $(p, \rho, v_x, v_y, v_z, B_x, B_y, B_z)$
    - 2-fluid: Neutral particles do not feel electromagnetic forces and may move differently from charged particles so collision rates between charged particles and neutral particles may not be the same like inside one specie. We consider the fluid variables (p, ρ, v_x, v_y, v_z) different for charged and neutral particles. A system of 13 unknown variables.
    - furthermore we could split the charges into ions and electrons as sometimes forces act differently on them or even consider each specie of ions in order to gain more resolution over the process

Partially ionized plasma

While 1fluid is a good approximation for photosphere (all neutral) or corona (all ionized) it might not be so precise for the chromosphere and transition region where plasma is partially ionized and we try to apply the 2 fluid approximation

- integrate numerically the 13 equations in order to get time evolution
- initial conditions based on observations

By having more knowledge of the evolution of different kind of particles we hope to understand better things that are not very clear yet like the wave propagation in the sun atmosphere or the heating in its upper part.

Simulation

- generation of initial conditions (python)
- executing fortran 90 parallel code which solves the PDE system and outputs the results in hdf5 files
- visualization and analysis (visit or python)
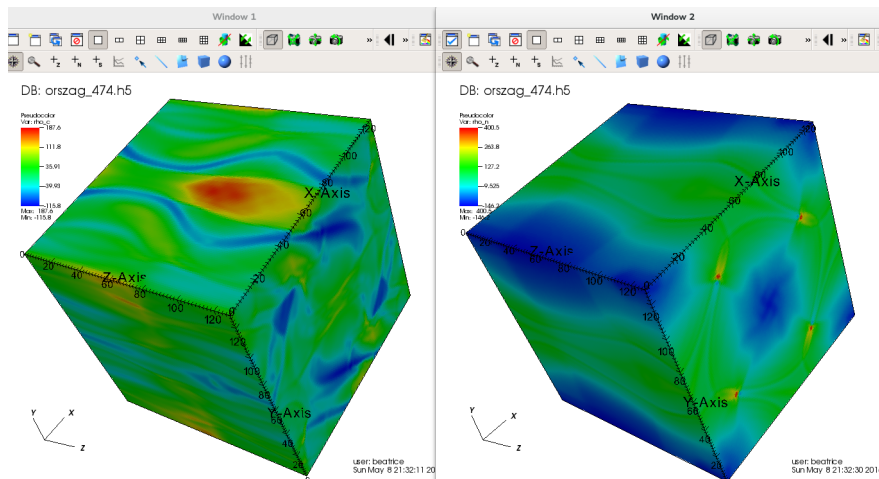
Test result in visit

Figure 4: density of charges and neutrals in Orszag test after 474 iterations where they evolve independently (collision terms between neutrals and charges are set to 0)